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DEVELOPING A SAMPLING PROTOCOL TO ENHANCE THE PROFITABLITY OF FLAX FIBER PROCESSING

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Developing a Sampling Protocol to Enhance the Profitability of Flax Fiber Processing

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Final Report

Biolin Research Inc.

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Project Title: Developing a Sampling Protocol to Enhance the Profitability of Flax Fiber Processing

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Abstract

The objective of this research project was to develop sampling protocols that can be used to produce statistically valid composite samples of flax straw from fields, groups of bales or single bales. Fields and bales of oilseed flax were sampled in the Redvers area of Saskatchewan in October 2002 and the straw collected was analyzed for bast fiber content using NIR and manual methods. A statistical analysis of the results shows that 50 to 200 samples should be taken from a 160 acre (64 ha) field and 1 to 18 samples should be taken from single bales. The number of required samples depends on the desired co-efficient of variation (CV) and the natural variation that occurs in the field.

Executive Summary

The impetus for this research project was the lack of a rapid and accurate method to determine the fiber content of the straw in a flax field, a group of flax bales or even a single bale being considered for use as a source of fiber by fiber processors. This, in turn, led to the need to develop faster testing methods for bast fiber content and statistically valid methods to create representative composite samples of flax straw in bales and fields. The objective of this research project was to develop sampling protocols to enable the collection of statistically valid representative straw samples from flax fields and groups of flax bales.

In the fall of 2002, Biolin Research collected flax straw samples from 17 fields and from bales removed from 4 fields in the Redvers area of southeast Saskatchewan. Straw yield and seed yield data were collected. All samples were then tested for fiber content using a Near InfraRed (NIR) system of testing for flax fiber developed by Biolin jointly with the USDA's Russell Research Center in Athens, Georgia. More than 100 samples were also tested by water retting and extracting the fiber by hand as a check of the NIR system.

A statistical analysis of the variance in fiber content between samples within each field and within each group of bales was undertaken to determine the number of samples that it would be necessary to collect to provide a statistically valid sample of a field or group of bales that would have a co-efficient of variation (CV) of 10%, 15%, or 20%. Several regressions using dummy variables also were run to pinpoint statistically significant differences between selected characteristics.

One of the first things that became clear from the results of the sample testing and analysis was that the variation in bast fiber content, straw yield and seed yield is far greater than initially anticipated. The number of samples that need to be collected to represent a field or group of bales depends, to a very large extent, on the expected variability of the property in question (e.g., bast fiber yield) and on the accuracy that is required. The more accuracy that is required, the more samples are required and, hence, the more time and expense involved in collecting, transporting and analyzing the samples. Ultimately the end-users of the data generated have to decide how much accuracy is required for a given application. Table 1 provides a summary of the number of samples to be taken when using the suggested sampling protocols.

The most immediate impact of this project is that a large number of observations have been added to the NIR database to improve its predictive accuracy. The development of valid field and bale sampling protocols, combined with Biolin Research's NIR system for measuring bast fiber in flax straw samples, will enable producers, processors, and researchers to make improved estimates of the fiber expected in flax fields and groups of bales before harvest or processing. The information from this project, hopefully, will be used to develop an American Society for Testing and Materials (ASTM) industry accepted "guideline" or "practice" for collecting representative samples of flax straw in fields and bales. This, in turn, will also help flax straw processing companies become more consistent in their procedures and help them become eligible for ISO certification; a step that improves the marketability of their products. If flax processing expands in Saskatchewan, it can be expected that there will be positive impacts on income of flax producers, rural employment and the environment.

Table 1. Number of Sampling Sites Required for Representative Samples of Fields and Groups of Bales Based on Flax Fields and Bales Sampled near Redvers, SK in 2002.*

	Desired CV (%)		
	10	**15**	**20**
Recommended field sampling protocol			
- number of samples per field	200	100	50
Recommended bale sampling protocol (group of 20 bales)			
- number of samples per bale	4-8	2-4	1-2
Recommended bale sampling protocol (single bale)			
- minimum samples per bale	1	1	1
- maximum samples needed by 95% of bales	11	5	3
- maximum samples per bale	18	7	4

* For each composite representative sample we need 350 – 400 stems. Thus, the number of stems to be collected at each sample site can be calculated by taking 400 and dividing by the number of samples required. (NOTE: If possible, all stems should be at least 19 cm long.)

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Background and Objectives

Background

Farmers in Western Canada seed 700,000 to 900,000 hectares of flax every year and produce 800 to 1,600 kg/ha of "salvageable" straw in a normal weather year. Only 10-20% of this straw is collected, primarily for its fiber, and used in the manufacture of specialty papers and plastic components. Dealing with the flax straw that is not removed from the field is problematic for farmers because it does not break down easily. The flax straw that is not removed from the field is normally burnt or chopped and spread. Unfortunately, burning creates negative environmental impacts and chopping and spreading has a financial cost.

Recent market surveys and on-going research indicates there are many potential products that could utilize flax fibers to complement or replace glass, synthetic and cotton fibers. The non-fiber portion of the straw (the shives) also has economic potential. Using the components of flax straw more extensively in a variety of products would increase the demand for flax straw, thus increasing farmers' income from growing flax by reducing straw management costs and, possibly, producing revenue from the sale of the straw. It also would reduce the amount of flax straw that is burnt and the resulting negative environmental impacts.

Prairie farmers currently receive very little financial compensation for their flax straw when it is collected for further processing. They often consider it a benefit just to have it removed at someone else's expense without being paid for it. The processors who collect flax straw on the prairies are primarily collecting it for its fiber. They are not producing high value products with this fiber and their costs of collection are high so they are unwilling to offer very much money for the straw. In addition, the high costs of collecting straw restrict the area from which they can collect it. The straw currently salvaged on the prairies is collected from small geographical areas near straw processing facilities.

A first step toward raising the average per tonne value of flax straw for both farmers and processors is to find ways to better quantify and qualify any valuable components that are found in it. At the present time, the bast fiber has been identified as the straw component that will most likely lead to a value-added industry with the largest commercial potential. In order to realize the economic potential of flax fiber production, it is necessary to be able to accurately determine the amount of fiber produced in any given field of flax before the straw is collected. If the fiber content in fields was known before straw collection took place, the processors could collect fiber more cost-efficiently and farmers who manage their oilseed flax straw to improve the fiber content could be correspondingly financially compensated.

It would be to the processors' advantage to collect straw from the fields where the fiber content of the flax straw is the highest among the fields available to them, since this would reduce the costs of collecting and processing a given amount of fiber. This would also benefit farmers with high fiber flax straw because the processors could afford to pay more for this straw. At the present time, processors do not have a good method of evaluating the amount of fiber in a field so cannot choose among fields and pay differential amounts for flax straw based on fiber content. They need the ability to collect representative samples of straw in the field to use in tests to establish the amount of fiber available to them.

Techniques for producing representative samples of flax straw in the field become increasingly important when one moves up the value chain and, hence, for processors who are trying to produce higher value end products. Ultimately, good sampling techniques allow processors to more consistently pick high fiber content fields and bales and produce higher value products, hence, allowing them to pay a higher price for flax straw. This information was not, regrettably, available to Durafibre during its years of operation. It unfortunately purchased large quantities of flax straw that had low fiber content and only in the last couple years of operation did a few of the staff start to realize the importance of having truly representative samples of fields and bales of straw. They did not, however, develop protocols to do this.

Biolin Research over the last several years has jointly developed a system with the USDA's Russell Research Center in Athens, Georgia which uses Near InfraRed (NIR) technology to determine the bast fiber content of flax straw samples relatively quickly and cheaply. However, the commercial usefulness of this testing system depends on ensuring that straw samples collected for testing are truly representative of the straw grown in the field from which the samples come.

As part of the development of an NIR system of measuring flax fiber, Biolin Research first developed a "wet chemistry " protocol to manually extract bast fiber from flax straw. In this wet chemistry protocol, flax straw samples are warm water retted to the optimum retting point identified by using the Fried Hot Water Shake Test. After this point is reached, the retted straw is rinsed and dried. A reciprocating blade decorticator is then used to assist in the hand separation of the bast fibers from the retted straw. The weight of the clean extracted bast fiber is then divided by the beginning weight of the unretted straw and multiplied by 100 to give a bast fiber content in percentage terms.

The Near InfraRed (NIR) methodology used by the USDA Russell Research Lab to quickly estimate fiber content in flax straw was obtained along with the initial estimated equations which link NIR wavelengths to bast fiber in flax. These estimates were based on 200 samples of unretted flax straw and the subsequently extracted bast fiber that was supplied by Biolin Research. In the fall of 2001, Biolin began working in collaboration with the University of Saskatchewan Crop Development Center (CDC) to adapt this methodology to work on a NIR machine owned by the CDC that is the same brand and model as the one used in the Athens lab.

Many unretted straw samples have now been scanned using the CDC NIR machine before being water retted. The scan results have been entered into a NIR software database along with the subsequent bast fiber contents calculated using the manual extraction method for determining bast fiber content. The resultant NIR database needs improvement and fine-tuning but can now be used to predict bast fiber content in unretted flax straw with a reasonable degree of accuracy. Biolin is continuing to add to this database and to improve its predictive accuracy.

The testing for bast fiber content in flax straw has advanced to the point where it can be used in both research and commercial applications. However, a reliable, repeatable testing method is relatively useless without combining it with a statistically valid sampling protocol. Similarly, a statistically valid sampling protocol is relatively useless unless it can be combined with a good testing method. Consequently, focus needs to be placed on developing protocols that will ensure that statistically valid representative samples can be collected for testing purposes.

With this in mind, Biolin applied for funding to carry out several tests and collection trials aimed at developing statistically valid sampling techniques for flax straw in fields and in bales. Funding was eventually secured from the Saskatchewan Flax Development Commission and the Agriculture

Development Fund of Saskatchewan Agriculture, Food and Rural Revitalization in 2002. What follows is a description of the collection, testing and analysis work that was carried out as well as the preliminary conclusions regarding protocols to collect representative samples of flax straw from fields and round bales.

Biolin Research can help other existing and potential new flax straw processing companies improve their chances of profitably producing flax fiber for higher end uses by making these statistically valid sampling techniques available. Biolin researchers hope to use the information from this project to develop an American Society for Testing and Materials (ASTM) industry accepted "guideline" or "practice" for collecting representative samples of flax straw in fields and bales. This, in turn, will also help flax straw processing companies become more consistent in their procedures and help them become eligible for ISO certification; a step that improves the marketability of their products.

Objectives

The objective of the research described in this report was to develop a flax field sampling protocol that will give buyers, sellers, processors and researchers who use flax straw, sub-sampling techniques that they can use to produce a truly representative sample of flax straw from a field or group of bales.

This project met this objective by carrying out enough sampling and property testing so that statisticians could calculate the minimum number of sub-samples and the pattern of sub-sample collection that must be carried out to give such a representative sample.

Experimental Methods

- Personnel from Schweitzer-Mauduit (SM), a company with a long history of processing flax straw in Saskatchewan and Manitoba, arranged for Biolin Research technicians to sample fields in the Redvers area of southeast Saskatchewan where SM commonly purchases flax straw for processing. Eight fields of flax grown on level topography, five fields grown on slightly rolling topography and four fields grown on undulating (hilly) land were selected for sampling.
- Just before harvest, during harvest, or immediately after harvest in 2002, 30 samples of straw were collected from sites distributed throughout each field. A one quarter square meter area of flax straw was pulled at each sample location. A simple GPS reading also was taken at each field sample site.
- After Schweitzer-Mauduit's custom balers baled the straw, 6 samples were taken from each of 20 bales in each of 4 sampled fields.
- All straw samples were taken to Biolin Research in Saskatoon and stored.
- Seed yields were collected from the straw samples from uncombined fields. Straw yields (i.e., weight) from each sample were also measured.
- Sub-samples were prepared from each straw sample collected from fields and bales. From each field sample, a sub-sample bundle of straw 4 cm in diameter and 19.0 cm long was cut 10.0 cm above the ground line. In cases where the samples were very short, the 19.0 cm section had to come from closer to the ground line than 10.0 cm. From each bale sample, a bundle 4 cm in diameter and 19.0 cm was prepared. After bundling, each sub-sample was bound with two elastic bands and tagged with a label.
- Biolin technicians scanned each sample for fiber content using the NIR machine at the University of Saskatchewan. Data from scans was manipulated with NIR scanning software by University of

Saskatchewan Crop Development staff. Computer generated results were then sent to Biolin technicians.

- One hundred samples were also water retted, rinsed and dried and had the bast fibers extracted by hand. The manual extraction of the fiber served as a check of the accuracy of the NIR estimates and was also used to add observations used in the calibration database that must be used in conjunction with the NIR machine.[1]
- Data from the above testing was entered into Excel spreadsheets, sorted and analyzed for statistically significant results using regression analysis with binary variables. Variance in seed yield and straw yield were analyzed and compared with variance in fiber yield.
- A statistical analysis of the variance in fiber content between samples within each field and within each group of bales was undertaken to determine the number of samples that it would be necessary to collect to provide a statistically valid sample of a field or group of bales that would have a co-efficient of variation (CV) of 10%, 15%, or 20%.
- A report was written which summarizes the experimental and analytical processes undertaken in the project and the results of this research. The report also presents protocols for collecting statistically valid representative samples of flax straw from flax fields and groups of flax bales which can be used by flax producers, flax processors and researchers for testing purposes.

Test Results and Discussion

Test Results

The field sampling data, the results generated from the NIR testing of each field and bale sample for fiber, and the equations and results from the statistical analysis of the field and lab data are presented in tables found in the Appendices. In addition, rough field maps were prepared (based on the GPS readings) showing the approximate position of each sample taken as well as its proximity to sloughs, trees, etc. These maps are available to readers who are interested.

Discussion

Theoretical Discussion

One of the main challenges in developing a sampling protocol is to find an acceptable trade-off between accuracy and cost. For example, in a "quarter section" (64 ha) field, a highly accurate composite sample could be created by taking a handful of standing straw from every square meter of field. Such a sampling procedure would be very representative of the field but the cost to collect and analyze such a large quantity of straw would be horrendous. At the other extreme, one could sample a quarter section field by taking one handful of straw from a location in the field deemed to be "typical."

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[1] Both the NIR and manual systems are subject to both random and systematic errors and bias. This is a common phenomenon with the vast majority of test methods and procedures. During the course of the research, fiber test results were periodically scrutinized for anomalies and the straw from any suspect results was re-tested if possible. Generally, the manual method showed somewhat more variation in the bast fiber contents that did the NIR results. However, the overall means of all of the NIR and manual samples were almost exactly the same. It is not unusual for the NIR results to show somewhat less variation than results obtained manually because there are more steps involved in most manual methods. The more steps involved in a procedure the more chance there is that the technician or the devices involved will introduce errors into the result.

The collection and analysis of this one sample would be relatively very inexpensive, but the results from this one sample would likely be highly inaccurate in comparison to the results when all the straw was collected and processed for a commercial application. Ultimately, one wants to minimize the samples taken because this will minimize the cost and time needed to collect and analyze the samples. However, the number of samples must be sufficient to accurately represent the field or bales that they come from.

The minimum number of samples that must be collected is often a function of the variation in the field (or group of bales) and the degree of accuracy that one needs. The variation in the properties to be tested (e.g., fiber content) will usually increase as the field size or number of bales increases. More samples need to be taken from fields or bales that show large variations (e.g., hilly areas, saline patches, old manure piles, many colors of straw) compared to fields or bales that show little variation in appearance or properties.

The degree of accuracy is a concept that is sometimes more difficult to understand. Generally, the more accurate or repeatable we want the results to be, the more samples we have to take. This is because collecting samples from a field or row of bales is never a perfect substitute for collecting all of the straw in the field or row of bales. The samples that are collected are almost always somewhat different from the whole field or row of bales by some margin of error. The trick is to make the sample as accurate as one can by keeping the error small.

There are several mathematical formulas that have been developed to indicate how close a particular set of examples come to representing a total population (in our case, the total population is a field or a row of bales). One of the formulas is the "coefficient of variation" or CV. The formula for calculating this is:

$$CV = \frac{SD}{\bar{x}}$$

$$Where: SD = standard\ deviation,\ and$$

$$\bar{x} = the\ mean$$

In this formula, the SD is calculated thus:

$$SD = \sum_{i=1}^{n} \sqrt{\frac{\left(x_i - \bar{x}\right)^2}{n-1}}$$

$$Where: n = the\ number\ of\ samples,$$

$$and \quad \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

In simple words, the lower the CV, the greater the probability that repeated sampling from the same field or row of bales will give similar results (i.e., the lower the CV, the more truly representative the sample).

When plant scientists set up replicated plots to test for differences in treatments (e.g., varieties), they often want a CV of 0.10 (i.e., 10%) or less between replicates of a similar treatment so that they have a

high probability of detecting statistically significant differences between treatments. In the case of sampling fields and rows of bales, we are using the CV calculations in a different way but it is useful to point out that many plant scientists do consider a CV of 0.10 to be a useful statistical cut-off. When sampling fields and bales, the lower the CV value we want, the more samples we must take. Once we know the variability (i.e., the standard deviation) that exists in the straw of a field or a row of bales, we can calculate the number of samples needed to give us a specified CV value. Algebraically, we can manipulate the formulas for CV and SD in the following way to calculate the number of samples (N) needed. First, we need to calculate the "sums of squares of deviations" $(x_i - \bar{x})^2$ that is generated when statistical packages calculate the SD:

Since

$$SD = \sqrt{\frac{(x_i - \bar{x})^2}{n-1}}$$

then

$$(SD)^2 = \frac{(x_i - \bar{x})^2}{(n-1)}$$

therefore $(x_i - \bar{x})^2 = (n-1) * SD^2$

This value for $(x_i - \bar{x})^2$ can now be used in the following formula:[2]

$$CV = \frac{SD}{\bar{x}}$$

or

$$CV(\bar{x}) = SD = \sqrt{\frac{(x_i - \bar{x})^2}{N}}$$

or

$$(CV(\bar{x}))^2 = \frac{(x_i - \bar{x})^2}{N}$$

or

$$N = \frac{(x_i - \bar{x})^2}{(CV(\bar{x}))^2}$$

Let us illustrate this with an example of a field where the mean $\bar{x}$ of the bast fiber content from 30 samples in the field is 13.2% and the variability as measured by the SD is 2.69. First we need to calculate the $(x_i - \bar{x})^2$ term:

[2] For samples greater than 30, statisticians normally divide the sums of squares by N rather than (n-1)

$$\left(x_i - \bar{x}\right)^2 = n-1(SD)^2$$
$$= (30-1)(2.69)^2$$
$$= 209.85$$

Now if we wanted to ensure a CV of 0.10, the number of samples we would have to take would be:

$$N = \frac{\left(x_i - \bar{x}\right)^2}{\left(c.v.(\bar{x})\right)^2}$$
$$= \frac{209.85}{(0.10(13.2))^2}$$
$$= \frac{209.85}{1.74}$$
$$= 121 \; samples$$

It should be noted that in this project we took 30 samples in each field. The above calculations assume $\bar{x}$ and SD would remain constant as more samples are added. This would be only true if the 30 samples already chosen are, in fact, a perfect representation of the mean and variation that would be produced if the entire field were sampled. This is, of course, extremely unlikely because the above calculation has shown we would need at least 121 samples to represent the field with a CV of 0.10. In reality, the only way to check if this is in fact true would be to repeatedly take several hundred samples from the same field and then analyze how much variation there is in the $\bar{x}$ and the SD between different sample sets. However, such an elaborate, time-consuming and expensive test is beyond the scope of this project.

In the above example, we can easily show how the number of samples required depends on the accuracy desired, by substituting different values for the CV and re-calculating the size of the sample required. Table 2 summarizes the results of this procedure carried out for a number of CV values with a mean bast fiber content of 13.2%.

Table 2. Effect of CV and SD* on the Number of Samples Needed for Statistical Validity.

13.2% Mean Bast Fiber Content			
Desired CV	**Number of Samples Required**		
	SD = 2.6	**SD = 3.6**	**SD = 1.6**
0.05	447	862	170
0.10	113	216	43
0.15	50	96	19
0.20	28	54	11
0.25	18	35	7
0.30	13	24	5

* The authors used SD = 3.6 and SD = 1.6 for illustrative purposes only. Higher and lower values for SD could have been used to illustrate the same point.

The table also shows how the number of required samples will increase if the variability in the field (represented by the standard deviation or SD) increases (e.g., SD = 3.6) and will decrease if the variability in the field decreases (e.g., SD = 1.6).

Thus, the number of samples that needs to be taken to represent a field or row of bales depends, to a very large extent, on the expected variability of the property in question (e.g., bast fiber yield) and on the accuracy that is required. The more accuracy that is required, the more samples are required and, hence, the more time and expense involved in collecting, transporting and analyzing the samples. Ultimately the end-users of the data generated have to decide how much accuracy is required for a given application.

Discussion of Research Project Results

Sampling Results

One of the first things that became clear from the results of the sample testing and analysis was that the variation in bast fiber content, straw yield and seed yield is far greater than we initially anticipated. In most fields, it was quite common to find CV values between 20% and 30% for each of these properties, but in the extreme, there were CV values that were almost as low as 10% and almost as high as 50%.

As an illustration, consider field DF 01-08-33-W1. When the 30 samples taken from this field were analyzed, the one half square meter salvaged straw weights averaged 47.9 grams with a SD of 11.8 grams and a CV of 27.49%; the adjusted local NIR fiber content of unretted straw (bast fiber content) had an average value of 13.5%, a SD of 1.69% and a CV of 11.69%; and the calculated bushels per acre had an average value of 22, a SD of 7 and a CV of 34%. Is such a CV for seed yield unreasonable? The data shows that the bushel yields were as low as 7 bushels per acre and as high as 43 bushels per acre with an average yield for the whole field of 22 bushels per acre. Anyone who has combined a hilly field could easily believe that seed yields could vary this much between thin spots and the heaviest spots.[3] Thus, the variation in seed yields and the resultant seed yields for the field seem reasonable. Unfortunately for sampling protocols, such high CV values imply that many samples will need to be collected to get truly representative samples of such a field.

All of the fields were in the Redvers area of southeast Saskatchewan and all had been selected by staff of Schweitzer-Mauduit (SM) of Winkler, Manitoba as being sufficiently tall and weed free to be used for a supply of straw for their processing plant. Although the SM staff were very co-operative, there were several breakdowns in communication between the Biolin staff, head office staff of SM and the SM straw buyers. On the positive side, Biolin staff were able to sample 17 fields instead of the anticipated 14 fields. On the negative side, Biolin staff were not able to sample bales from all of the fields because private bale-hauling contractors started hauling bales to the SM bale yard before SM staff notified Biolin that the baling of certain fields had already been completed. Since Redvers is at least a five-hour drive from the Biolin lab in Saskatoon, Biolin staff relied on information from SM staff regarding when the private contractors finished particular fields. Thus, fewer than anticipated bales were sampled. Fortunately, the results from the bale samples were relatively consistent and many preliminary conclusions can still be drawn from the data and analysis generated by the bale samples.

[3] The field in question was classified by Biolin technicians as being hilly relative to other fields they classified as rolling or flat.

To further understand the type of variations that were occurring and the reasons why, Biolin technicians collected simple GPS co-ordinates at each position where a straw sample was taken. These were then used to make rough maps of each field that showed the approximate position of features such as sloughs, trees, and building sites and where each straw sample was taken. These maps are available to interested readers but were not included in the electronic version of the report because of the large amount of electronic memory required.

Regression Results

In addition, several regressions using dummy variables were run to pinpoint statistically significant differences between selected characteristics. The full results of these regressions are shown in Appendix C, but the following discussion summarizes these regression results.

In the first regression, C1, [Fiber Content (%) = $f(\ )$ of Field Location], we compared the average fiber content of each field. There were statistically significant differences[4] among many of the fields with the lowest average fiber content being 9.1% and the highest being 15.3%.[5] The Adjusted R Square for this simple equation was 0.26. This result combined with many significant "t statistics" indicates that location of fields generally has a significant impact on the average fiber content of the flax straw and, hence, that selection of the location of fields often has a significant impact on the fiber content of the flax straw that a processor will buy. For instance, the four fields with the highest fiber content that were sampled (i.e., 4 out of 17 or 23.5%) had an average fiber content that was 42% higher[6] than the four fields with the lowest fiber content. Location is no doubt important because in this type of regression it indicates the combined effects of growing season weather with such factors as initial soil moisture conditions, previous crops, agronomic practices, etc.

In the second regression, C2, Fiber Yield (kg/ha) = $f(\ )$ of Field Location], we compared the estimated average potential amount of bast fiber that could be salvaged from each field. The estimated potential amount of bast fiber that could be salvaged is calculated from the average weight of salvageable straw that is produced multiplied by the bast fiber content.[7] All the fields were statistically significantly different from the field chosen as the intercept, with the best field generating an average of 260 kg/ha of potential bast fiber and the poorest field generating an average of 106 kg/ha of potential bast fiber. Once again, these results indicate the location of fields has a significant impact on the potential bast fiber that a processor can ultimately extract. For instance, the top four fields had an average potential bast fiber yield that was 86% higher[8] than the four fields with the lowest potential bast fiber yield. This result is even more extreme then when only the fiber content is considered. This is because potential bast fiber yield shows the combined effects of higher fiber content and higher salvageable straw yield (i.e., most of the fields with higher potential bast fiber yields have higher than average fiber contents and higher than average straw yields). These results reinforce the conclusion drawn previously that the correct selection of fields will have a very significant effect on the amount of bast fiber that a processor can obtain from a given area of land.

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[4] In this report we used the t-statistic at 95% to indicate statistical significance.

[5] Calculated by taking the intercept term (13.5%) and adding the corresponding regression coefficient for each field.

[6] [(15.3+15.2+14.2+13.8)/4]/[9.1+10.3+10.6+11.1)/4]*100

[7] The actual amount of bast fiber a processor can extract also depends on the degree of retting of the straw and the physical dimensions of the pieces of straw. The less retted the straw and the more "broken up" the straw, the more difficult it is to extract the bast fiber.

[8] [(260+211+203+200)/4]/[106+115+122+129)/4]*100

In the third regression, C3, [Change in Fiber Content (%) = $f(\ )$ of Harvest Status] we compared the bast fiber content between fields that had already been harvested at the time of the straw sample collection with those that had not been harvested. Those that had already been harvested had an average of 12.8% bast fiber content compared to the 11.89% fiber content of those that had not been harvested. Although this difference is small, it was statistically significant. There are many reasons that this might occur. Fields that had been harvested at the time of straw sampling may have been seeded earlier, seeded to earlier maturing varieties, had less rain, less nitrogen fertilizer, been planted in better drained fields, etc.

In the fourth regression, C4, [Fiber Yield (kg/ha = $f(\ )$ of Harvest State] we compared the potential average amount of bast fiber that could be salvaged from harvested and unharvested fields at the time of straw sample collection. The harvested fields had a potential average bast fiber content of 146 kg/ha compared to 198 kg/ha in the harvested fields. This difference was statistically significant. Although the unharvested fields had somewhat lower fiber content (see Regression C3), they appear to more than compensate by having a higher amount of salvageable straw. Unfortunately, we do not know if this is because the straw in the unharvested fields was taller[9] or because the cutting of the unharvested straw in the lab was closer to the bolls than normally happens when farmers put flax through their combines.

In the fifth regression, C5, [Fiber Content (%) = $f(\ )$ of Field Geography] we tested whether topography influenced bast fiber content. The results showed that fields classified as flat by Biolin technicians had an average of 13.2% bast fiber compared to 12.3% for fields classified as hilly and 12% for fields classified as rolling. Although these are small average differences, the "t statistics' indicate that these means are statistically significantly different.

Regression C6, [Fiber Yield (kg/ha) = $f(\ )$ of Field Topography] was similar to Regression C5, however, it compared potential bast fiber yield with topography. It showed that flat land had an average bast fiber yield of 147 kg/ha compared to an average of 188 kg/ha for hilly fields and 160 kg/ha for rolling fields. The yield from the rolling fields was not significantly different from the yield from flat fields.

Both regressions C5 and C6 indicate topography can have an influence on fiber content and per hectare potential bast fiber yields, but we do not know for sure if the results obtained were directly associated or correlated with topography. For example, hilly fields may drain faster in the spring and, hence, be generally seed earlier or to later maturing varieties or have more nitrogen applied. These agronomic practices may be the real reason why there appears to be differences in fiber content and potential fiber yield based on topography.

In Regression C7, [Fiber Content (%) = $f(\ )$ of Soil Variation] and Regression C8, [Fiber Yield (kg/ha) = $f(\ )$ of Soil Variation] we tested whether samples taken near particular topographic features had different fiber contents and different potential bast fiber yields. The results showed that only samples taken near trees had significantly higher fiber content (14%) than the average of 12.3% for open fields. There were no significant differences between samples from sites on open fields, near developments (eg. building sites), near swamps or near water. The results also showed that only samples taken near swamps had significantly less potential bast fiber yield per hectare (141 kg/ha) than the average of 166 kg/ha for open fields. At this time, we can only speculate as to the reasons for these results. Samples taken near trees may show somewhat higher fiber content because the flax plants near trees may experience less wind and lower temperatures (i.e., shade) and, hence, less stress. Flax grown near

[9] Later seeded flax crops often have lower seed yields but are taller. However, this is only a tendency and not always the case.

swamps may have to grow in soil that is more saline and, hence, less conducive to the growth of vigorous plants.

In the ninth regression, C9, we tested whether the field means of fiber content had a significant effect on the number of samples needed to get a desired CV. The results showed no significant difference.

In the tenth regression, C10, we tested whether the field means of fiber content were significantly different depending on topography. They were not.[10]

In the eleventh regression, C11, we tested whether the fiber content CV was related significantly to the number of samples need to get a desired CV. After doing this, we realized the logic is flawed since the number of samples needed is a function of the desired CV. Thus, this regression should be ignored.

In the twelfth regression, C12, we tested whether the CV's of each field were significantly related to the topography of the field. We found no significant relationship. This indicates that, at least in the fields we sampled in the Redvers, Saskatchewan area, the topography of the field was not a good indication of the actual variation in fiber contents that occur in a field.

In regression 13, we looked at the fiber content in bales that had been made from four of the fields that had been previously sampled. The mean fiber content ranged from a high of 19.8% to a low of 17.7% and all fields were significantly different. This, once again, points out that location has an important impact on fiber content. When flax straw is combined and baled, some of the shives break off and fall on the ground, whereas most of the fiber tends to stay tangled in the straw that is eventually baled. Consequently, baled flax straw tends to have a higher fiber content than would be indicated by sampling standing straw or stubble. Table 3 shows the average fiber content of samples taken from a field before baling and samples taken from the bales obtained from the same fields. These results indicate that after combining and baling, fiber content can increase from roughly 50% to 70% over the fiber content found in a standing crop or stubble. This is a very significant increase and would significantly reduce the transport costs per tonne of bast fiber processed, since it shows that significant amount of shives are being knocked out of the straw and left in the field.[11]

Table 3. Mean Fiber Contents of Field and Bale Samples From the Same Fields.

	Bast Fiber Content (%)		
Field	**Field Samples**	**Bale Samples**	**% Increase**
KP SE-21-06-33-W1	11.8	18.9	+60%
DH E1/2-09-06-33-W1	10.6	17.7	+67%
KP SE 27-05-33-W1	12.8	19.6	+53%
MP NE-21-6-33-W1	13.2	19.9	+51%
Mean	**12.1**	**19.0**	**+58%**

In regression C14 we tested to see whether or not there was any significant difference in bast fiber content depending on where the sample was taken in the bales. Each bale was sampled in the same six places with samples 1 and 2 being taken in the center core of each butt end of the bales about 15 cm

[10] Regression C6 showed there were significant differences when all of the samples from all of the fields were put in a regression together. In regression C10 we only put the means of the fields in the regression.

[11] Whether or not it is profitable to leave some shives in the field will depend on the price the straw processing plant can sell the shives for.

inside the bales. Samples 3 and 4 were taken from the front and back of the bale on the left and right hand sides of the curved surface and samples 5 and 6 were taken on the surface of the butt ends. The two interior sampling positions (samples 1 and 2) had average bast fiber contents of 18.8% and 18.7% compared to the 19.4% average bast fiber content found on the outside surface of the bale (i.e., sample position 4).[12] This was a significant difference. The other three sampling positions from the surface of the bale did not show any significant difference from that found on the outside surface of the bale (i.e., sample position 4). Since the results show the combined effects from hundreds of bale samples, the effects noted almost certainly come from the actual baling process. We think the slightly lower fiber content in the core of the bales is the result of shives and dirt falling loose during the baling process. Since we are dealing with round balers, we know that the straw entering the baler is continually traveling around the inside of the bale chamber. Loose shives and dirt fall out of the cracks between the belts and chamber walls onto the ground. However, some also fall inward toward the core of the bale and cannot work their way out of the bale. As the bale forms, the shives and dirt caught in the interior would tend to decrease the measured fiber content. Conversely, the fiber content on the outside curved surface was slightly higher than average, probably because shives and dirt have fallen outside of the bale chamber and no shives and dirt have fallen into this layer from subsequent outer layers of straw. The following table illustrates how fiber content varied by sample position.

Table 4. Effects of Sample Position on Mean Fiber Content in Bale Sampling.

Sample Position	Mean Fiber (%)
Left - round surface	19.4
Right – round surface	19.4
Left – butt surface	19.1
Right – butt surface	19.0
Left – interior core	18.8
Right – interior core	18.7
Mean	**19.0**

Based on these findings, the samples taken from the surface of the butt sides had fiber contents most similar to the overall mean of all of the samples. Since the butt ends also offer, by far, the easiest way to sample different layers of the same bale, "hand-grabbing" samples along the butt edges probably offers the quickest sampling technique that will likely give the most representative samples.[13]

Protocols

Background

One of the objectives of this project was to develop a series of protocols or guidelines for use when sampling flax straw in fields or in rows of bales. In the case of the fields we sampled, we found that not only do individual fields have a very large amount of variation in the fiber content, straw yield and seed yield, but that there is also a big variation in the degree of variation that occurs among different

[12] One sample position (4 in this case) is chosen as the point of comparison in the regression analysis.

[13] We did not try a bale corer. Core samples would likely be even more representative but take longer to carry out than the "hand grabs" we tried. Core sampling flax straw with higher fiber content also may be difficult because of the resistance of the fibers.

fields. The calculated number of samples needed to represent a field varies with the variation in the field in question. Table 5 shows how there is a distribution (i.e., variation) in the amount of variation that occurs among fields. Such "variation in the variations" makes it more challenging to develop guidelines for sampling fields, but it, unfortunately, reflects the real life situation.

Table 5. Number of Samples Required to Collect Composite Representative Sample From Fields Sampled in the Redvers Area, October, 2002.

Original Field Number in Appendix*	Desired CV (%)		
	10	**15**	**20**
1	39	17	10
11	41	18	10
15	54	24	13
16	73	32	18
14	74	33	18
10	82	37	21
13	83	37	21
3	90	40	23
7	90	40	23
4	98	43	24
17	101	45	25
12	110	49	28
5	120	53	30
2	195	86	49
6	198	88	50
9	203	90	51
8	443	197	111
Rounded Mean	**123**	**55**	**31**
Maximum samples needed:			
8 most even fields	98	43	24
8 most uneven fields	203	90	51
Most extreme field	443	197	111

* Ordered from least to most in this table by the number of samples required.

In the case of the farmland around Redvers, Saskatchewan (which is neither extremely even nor extremely uneven compared to some parts of the province), the topography of a given field was not a good indicator of the variation that would be present in the field. As flax plants grow and develop

fiber, there appear to be multiplicative factors at work influencing the ultimate fiber content in the stems. These might include such factors as localized differences in soil type and texture, pre-seeding and growing season rainfall, type and concentration of micro-rhiza beneficial or harmful to the flax plant roots, nematodes, type and numbers of weed and insect pests, previous crop residue concentration, shortages or "overlaps" of herbicides and fertilizers, grazing and manuring effects of wild animals and birds, rainfall run-off, etc.

Unlike most other commercial large-scale crops grown in western Canada, flax has a relatively shallow taproot. This, no doubt, makes it relatively more susceptible to very localized differences in many of the factors mentioned above. Consequently, it is not surprising that the results of our field sampling showed that, in many cases, more than 100 samples would be needed to adequately represent the variation in fiber content that can be expected in an average field of 120 – 140 acres (i.e., a quarter section of 160 acres or 64 hectares that has some sloughs – a situation typical of many fields in the Redvers area). There was considerable variation in the amount of variation that occurred in fields and, hence, to achieve a desired CV level, more samples need to be taken in fields that have relatively more variation. In addition, the more accurate we want our composite sample to be (i.e., the lower the desired CV), the more samples one must take. In an effort to better illustrate how the number of samples needed for a field varies because of the two just mentioned factors (i.e., variations in field "evenness" and desired CV level), Table 4 was prepared from the summary field data appearing at the end of each set of field data shown in Appendix A.

Protocol 1 – Sampling a Flax Field for Fiber Content if Time is Not Limiting

Discussion

If a quarter section (i.e., 64 ha) field is being sampled, the emphasis should be on taking many small samples at many locations evenly distributed in all areas of the field, rather than taking larger samples at a few sites. If one anticipates using the NIR or manual fiber testing methods used in this project, the total accumulated number of stems should be 350 to 400 at the most. Hence, if one stops at 50 sites, 8 stems would need to be collected at each site. If stops are made at 100 sites, only 4 stems would need to be collected at each stop. Since one often can't tell by topography how variable the field is likely to be, be conservative. Assume it is more variable than it appears. Based on this assumption, we will use the sample numbers from the bottom of Table 5 for the "8 most uneven fields" as a sampling guideline [14]

Guideline

Based on the required sample numbers for Table 5's "8 most uneven fields" and allowing for rounding of numbers to make them easy to remember, collect the following number of plant stems (at least 19 cm long for testing purposes) at each sampling site (Table 6). Contact Biolin Research in Saskatoon for details regarding tests for fiber content.

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[14] We should also assume there is more variation because in each of the fields we sampled we took only 30 samples and, hence, could easily have missed portions of the field that had more variation than we measured. We know now that many more than 30 samples should be taken to better estimate the true variation in bast fiber content that exists in a quarter section.

Table 6. Number of Sampling Sites and Number of Stems Required for a Representative Sample of a Field.

Desired CV (%)	Number of Sampling Sites	Number of Stems/Site
20	50	8
15	100	4
10	200	2

If one wants a higher degree of accuracy, one must spend more time walking in a tighter grid pattern so that there is a greater chance of sampling the true distribution of variations that exist in the field.

Walking Protocols

When sampling a quarter section field to get 50 or 100 samples, it is useful to have some walking guidelines so that roughly the same number of samples are taken in each part of the field. One possible way to collect 100 samples evenly spread across a square quarter section field would be the following (illustrated in Figure 1):

1. from the corner of the field, walk 130 feet in a diagonal toward the opposite corner of the field;

2. pick 4 flax straw stems at least 19 cm long;

3. walk 260 feet parallel to the straight edge of the field;

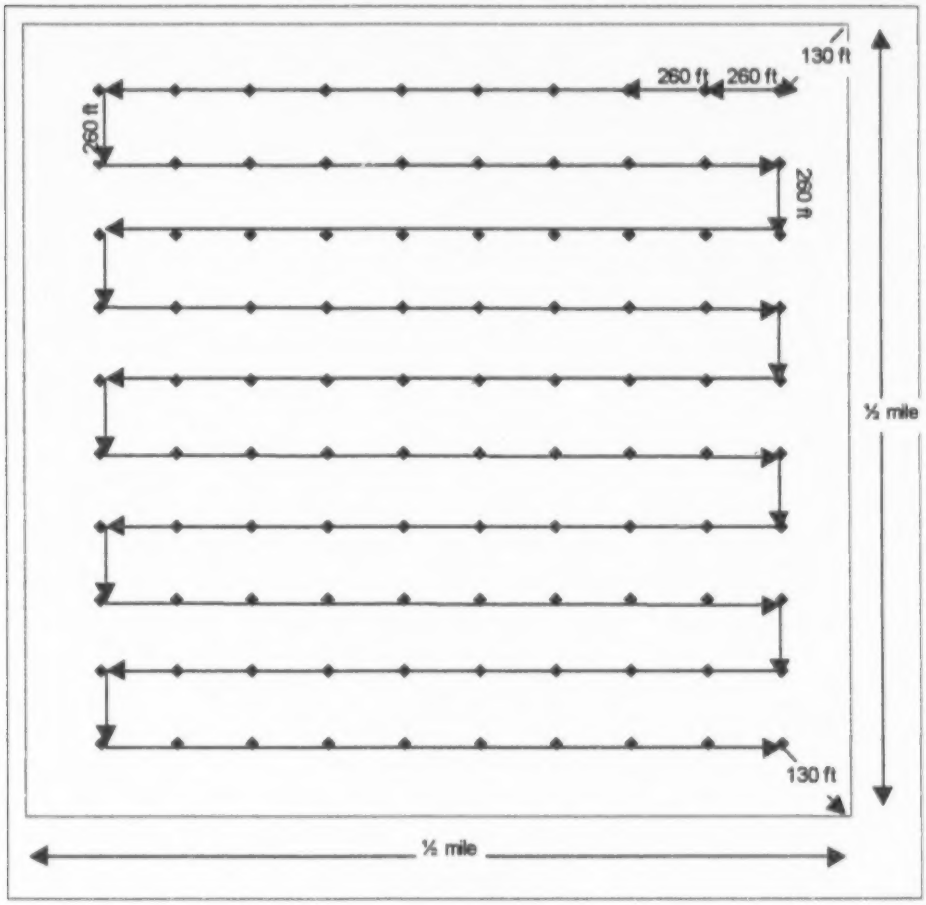
4. repeat steps "2" and "3" until you have made a total of ten stops and have a total of 40 stems. This should bring you to the edge of the field;

5. walk 260 feet at a 90° angle to the direction traveled in step "4" so that you will be walking toward the unsampled part of the field. At this point, make another 90° turn so that if you continue to walk straight ahead you will be walking parallel to, but in the opposite direction to that taken in step "3";

6. repeat steps "2", "3", "4" and "5" until ten parallel walks have been made across the field, 100 sites have been sample and 400 stems collected.

Each person's stride is slightly different, but an "average" stride would be about 2.5 feet and takes about one second. Thus, 130 feet would be roughly 52 strides and 260 feet would be about 104 strides and would take about 104 seconds between each stop. 10 seconds should be sufficient to pull out or pick up 4 stems at least 19 cm long. At this example speed, collecting 100 samples will take about 11,400 seconds (114 x 100) or roughly 3.0 to 3.5 hours for 100 samples.

Figure 1: Sampling Protocol for 100 Samples Per Quarter Section



In the case of 50 sample sites, one can follow the same general pattern as that described for 100 samples but should walk diagonally in from the corner 190 feet instead of 130 feet and then walk 377 feet between sample sites instead of 260 feet. At each site take 8 stems instead of 4. At the walking speed suggested previously, and allowing 20 seconds to collect 8 stems, it should take about 8,500 seconds (171 x 50) or roughly 2.25 to 2.5 hours for 50 samples. Although this walking pattern for 50 samples saves about 45 minutes per field, there is a greater probability that it will produce a less representative field than when the 100 sample walking pattern is used.

Protocol 2 – Sampling a Field Quickly for Fiber Content But With Much Less Accuracy

Guideline

Select five sites in a field and pull handfuls of stems out of the ground. Rub the stems together repeatedly and tug on the two ends of the stems in an attempt to break them apart. If the straw at four or five of the sampling sites is hard to break, chances are the straw has relatively higher fiber content. If the straw easily breaks at four or five of the sampling sites, chances are the straw has quite low fiber

content. In cases where the results are not clearly one way or the other, walk through the field in a zigzag pattern, stop at least 25 times and take 6 straws at each stop.[15] Note that accuracy will be improved by walking in a tighter grid pattern and taking 3 stems at 50 sites. After collecting the straw, contact Biolin Research for details regarding tests for fiber content.

Protocol 3 – Sampling a Group of Flax Bales for Fiber Content

Discussion

A single bale contains the straw from a small section of a field and, hence, the extremes of values found in a large field are unlikely to be found in a single bale.[16] However, there can still be surprisingly large variations in some bales. Table 7 was prepared from the summary bale data appearing at the end of each set of field and bale sampling data shown in Appendix A.

Table 7. Number of Samples Needed Per Bale When Sampling 20 Bales.

Original Order in Appendix A	Desired CV (%)		
	10	15	20
1	6	3	2
2	8	4	2
3	4	2	1
4	4	3	2
Mean	**5.5**	**3.0**	**1.75**
Minimum required	**4**	**2**	**1**
Maximum required	**8**	**4**	**2**

Given the wide variation in fiber content we have found in fields, it is far better to sample every bale in a row of 30 bales at least once rather than taking many samples from three bales out of the thirty. This is because the greater number of bales we sample, the greater the chance that we are getting samples of straw from all over the field that was the source of the bales. The previous table shows we should take at least one sample per bale and a maximum of two samples per bale if we want a CV of 20% and we have at least 20 bales to sample. Now if we have to deal with a row of flax straw bales from a quarter section (64 ha) field, should we still take two samples per bale? Schweitzer-Mauduit expects an average of 600 kg/acre of straw and their bales weigh about 545 kg/bale. If, on average, there are 140 planted acres in a quarter section, Schweitzer-Mauduit would get 154 bales. Even one sample per bale would generate 154 samples, however, our analysis of field variation showed that 50 samples would be sufficient to represent a quarter section field if a CV of 20% is adequate. Given this information, we could represent a quarter section by taking one sample from every third bale, if our straw yield and weight of bales were similar to those experienced by Schweitzer-Mauduit. If a larger number of bales were produced per quarter section field, a smaller percentage of bales would need to be sampled.

If one anticipates using the NIR or manual test methods used in this project to test for fiber content, the total accumulated number of stems should be 350 – 400 at most. Hence, if 50 bales are sampled from

[15] Thus, one will accumulate about 150 stems. Reducing the total accumulated stems speeds up the collection process slightly but will not provide any "backup" samples for re-testing.

[16] This is a general statement. If a bale were made from a strip of field that passes through a saline patch, a ditch, a hill and an old manure pile, it could show as much variation as a large field.

one field, only 8 stems would need to be collected from each bale. It is best to collect stems from the two butt sides of a round bale but if this is not possible, take stems from several widely separated spots on the round surface and recognize that the straw bast fiber content taken from these samples will be slightly higher than had butt side locations been used.

Guideline

If the sample to be tested is to represent a field of roughly 160 acres (64 ha), use the guideline for sampling a field to determine how many total samples to take. If possible, take the samples from the butt sides of the bale and take no more than one or two samples from one bale. In most cases, you will only need 8 to 4 pieces of straw at least 19 cm long from 50 to 100 bales. Contact Biolin Research in Saskatoon for details regarding tests for fiber content.

Protocol 4 – Sampling Single Bales

Discussion

At times, one may want to sample single bales or small groups of bales. In the case of salvaged oilseed flax straw, a 545 kg round bale can easily represent the straw from an acre (0.4 ha) or more of land and, hence, straw samples taken from single bales also show variation. The following table was prepared from data shown in Appendix A based on the details of each bale that was analyzed.

Table 8. Numbers of Samples Needed When Testing a Single Bale or Few Bales.

	Desired CV (%)		
	10%	15%	20%
Minimum needed	1	1	1
Maximum needed by 50% of bales	3	1	1
Maximum needed by 80% of bales	6	3	1
Maximum needed by 90% of bales	8	4	2
Maximum needed by 95% of bales	11	5	3
Maximum needed	18	7	4

This table shows that in out trials at least 50% of the bale samples were very consistent and, hence, 1 sample per bale would have been an adequate representation for a desired CV of 20% or 15% and only 3 samples per bale would have been needed for a desired CV of 10%. These bales came, no doubt, from very even parts of a field. However, we can see in Table 8 that if we want to increase the probability of adequately sampling all bales, we have to increase the number of samples taken. Thus, if we want to ensure that we have adequate samples for 80% of the bales, we would have to take 2 samples if we desire a 20% CV, 4 samples if we desire a CV of 15%, and 8 samples if we desire a CV of 10%.

It is interesting to note that in the most extremely variable bale, we should take at least 18 samples if we want a CV of 10%. This seems to point out that there are a few bales that have extreme variations and, if we take only a couple of samples from them, the results could be very misleading. If we are only sampling a few bales for a research project, we may as well be "as safe as possible" and take 11 to 18 samples per bale with each sample having 40 to 20 stems so we can get a composite accumulated

sample to be tested that would have 350 to 400 total stems[17] about 19 cm long. In many cases, taking 11 to 18 samples per bale would be "over sampling" since only a few bales showed relatively high variability, but if there are only a few bales to sample it would not take much longer to take, say, 20 stems from 20 sites in a bale rather than 400 stems from one site. Not only will collecting a relatively few stems at many sites not require much more time; it will also have a higher probability of being truly representative.

Guideline
If only sampling one or a few bales for a research project, be "as safe as possible" and take 11 to 18 samples per bale with each sample having 40 to 20 stems, to get a composite accumulated sample to be tested that would have 350 to 400 total stems about 19 cm long.

Conclusions and Impact

Conclusions

The impetus for this research project was the lack of a rapid and accurate method to determine the fiber content of a flax field, a group of flax bales or even a single bale being considered for use as a source of fiber by fiber processors. The goal of the research was to develop statistically valid flax field and bale sampling protocols.

In the fall of 2002, Biolin Research collected flax straw samples from 17 fields and from bales removed from 4 fields in the Redvers area of southeast Saskatchewan. All samples were then tested for fiber content using an NIR system of testing developed for flax fiber. More than 100 samples were also tested by water retting them and extracting the fiber by hand as a check of the NIR system.

Statistical analysis of the test results produced information which led to the development of protocols for determination and collection of the statistically valid number of sub-samples required to create a representative sample of the straw in a flax field or group of bales. These protocols were developed for the use of producers, processors and researchers to enable them to calculate and collect the necessary number and quality of sub-samples of flax straw needed to assemble representative samples of the straw in flax fields or lots of bales for various testing purposes (similar to soil testing a field, where 5 to 30 sub-samples are taken and then blended together to produce one truly representative sample of the field). The protocol will also be used as a base in the development of an American Society of Testing and Materials (ASTM) industry accepted "guideline" or "practice" for taking straw samples from flax fields and bales.

[17] The authors are assuming that there are times a second or third replicated or different test would need to be carried out. Strictly speaking, 100–120 stems is enough for one test, but it is far easier to collect more stems than are needed and not use them than to need 350-400 stems and not have them.

Impact

Economics

Existing fiber processors on the prairies have, in the past, had no accurate and rapid method of determining the fiber content of the fields of flax straw they wish to purchase. They have relied on past experience and cursory examinations of the fiber that can be rubbed out by hand after collecting a few samples because there was no other choice. The amount of fiber they might obtain from a given amount of flax straw (such as a field or a group of bales) can be highly variable and, as a result, they have not been willing to pay much for flax straw. Until now, the only industrial products produced from Saskatchewan flax fiber have been specialty paper products that can tolerate wide variations in shive and fiber content. However, there is pressure on these processors to produce fiber with a lower shive content. Choosing flax straw with a higher fiber content prior to processing is a first step in accomplishing this, since the original shive content will be lower. The processors must have better ways of sampling fields and bales to get truly representative samples of the straw they will be processing.

In the last few years, a number of provincial and international companies have started investigating the potential for processing Saskatchewan oilseed flax straw for higher end uses. To accomplish this, they will need to be much more particular about the fields of straw they process both from a cost and quality perspective. The inability to assess fiber content pre-processing has been a major concern of these processors. They are concerned about the lack of basic straw quality information and are worried about buying low fiber content straw.

The most immediate impact of the development of valid field and bale sampling protocols will be the ability to combine it with Biolin Research's NIR system for measuring bast fiber in flax straw samples to provide good estimates of the fiber expected in flax fields and groups of bales before harvest or processing. Processors will now be able to determine fiber content in the field or in bales by sampling and NIR testing. They will then be able to discriminate between flax fields, collecting the straw from higher fiber fields and, thus, obtaining more fiber per tonne of straw processed and lowering their costs of processing. This will improve the transparency and fairness of commercial transactions between buyers and sellers of flax straw (i.e., a farmer producing straw with a higher fiber content should get a higher price for his straw) and will provide a cheap and reliable tool that can be used to improve the fiber yield and/or consistency of the products the processors are producing.

Possible results of the adoption of this sampling and testing technique include:

- additional information will become available regarding the relationships between fiber yield and varieties, production practices, growing conditions, soil type and topography;
    - processors will further refine their field selection methods;
    - new processors may become interested in Saskatchewan as a source of flax fiber, increasing the demand for flax fiber; and,
    - producers may consider fiber content when choosing flax varieties, location of production and production practices;
- producers may capture a portion of the gains that accrue to processors from more cost-effective field selection and processing since processors may be willing to pay more for flax straw that has a high fiber content;
- processors may be able to produce a cleaner, higher-quality fiber (lower shive content) by being able to choose straw for processing that, on average, has higher fiber content than is the case now; and,

- the geographical area over which flax straw is salvaged may expand since high fiber flax straw outside the traditional collection areas may have more value even after transportation than low fiber content flax straw closer to the processors.

Environmental

- Increasing the amount of prairie flax straw fiber that is processed is a form of "carbon sequestration" since it reduces the amount of carbon released into the atmosphere by reducing straw burning.
- Increased flax straw processing may also reduce the need to use energy to produce glass fibers since natural flax fibers can often be substituted for glass fibers in industrial applications.
- Using an existing and under-utilized resource such as flax straw to produce fiber may also replace the demand for some wood fiber, decreasing the need to cut forests.
- More removal of flax straw from fields for processing may encourage farmers to leave the remaining straw as standing stubble as part of conservation farming systems.

Social

Increased production, collection and processing of flax fiber offers the potential of diversifying rural incomes by allowing processing activities to expand that can add much more value to rural areas than that of most seed crops. In the long run, this new development will expand the number of rural jobs revolving around the processing of flax fiber.

Market

Techniques for producing representative samples become increasingly important when one moves up the value chain and, hence, for processors who are trying to produce higher value end products. Ultimately, good sampling techniques will allow processors to more consistently pick high fiber content fields and bales and produce higher value products, hence, allowing them to pay a higher price for flax straw. Biolin can assist existing and potential new flax straw processing companies improve their chances of profitably producing flax fiber for higher end uses by developing industry accepted, statistically valid sampling techniques. Biolin hopes to use the information from this project to develop an American Society for Testing and Materials (ASTM) industry accepted "guideline" or "practice" for collecting representative samples of flax straw in fields and bales. This, in turn, will also help flax straw processing companies become more consistent in their procedures and help them become eligible for ISO certification; a step that improves the marketability of their products.

Information of Benefit to Processors and Government

Since this information shows that there is a wide range of bast fiber content possible in flax fields, it should encourage processors and/or governments to provide funding and/or other support to plant breeders to develop flax varieties for the prairies with elevated or lowered levels of bast fiber content depending on the expected end use of the straw. This information can also serve as the starting point for developing agro-climatic-soil maps, agronomic practice guidelines and processor/producer transactions and agreements that assist producers to maximize the market value of their flax production. Information that contributes to increased marketability and prices for flax straw and development of a flax processing industry in Saskatchewan will benefit government as they work to revitalize the rural economy and society.

The knowledge that the results of almost 1,000 new tests of fiber and shive samples are now available to better further calibrate the Biolin NIR system to quickly and cheaply measure bast fiber content in flax should encourage processors and governments to provide funds, if needed, to complete development of this method and/or to purchase and use NIR systems. This is an important step in the on-going process of identifying and developing the potential of Saskatchewan flax fiber production and processing.

Need for Further Research

The reader should note that the protocols for sampling described in this paper have been developed for land in the Redvers area of Saskatchewan. The fields sampled were in the black soil zone and were neither extremely flat nor extremely hilly. At this time, we cannot say with certainty that the results we obtained are typical of results that would be produced in other parts of the Prairies with the same or different topographical features and soil characteristics. At the start of the research, we thought that 30 samples per field should give a good representation of the variation that occurs in a field. We now know that, for the purposes of developing theoretically sound sampling protocols, we should take several hundred straw samples that are evenly spaced throughout the field.

All measurement protocols evolve over time as new information becomes available through further experimentation and collection of data. Biolin believes it has developed a sampling protocol that will enable processor, producers and researchers to collect valid representative samples of flax fields for various potential purposes, including for fiber testing. However, the process will continue to need fine-tuning and updating through the collection and analysis of more observations and data from a wider variety of geographical locations, soil types and growing conditions. Support from producers, the processing industry and government for this research will be important to ensure that the work can continue.